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Publication date:
2011

Document Version
Accepted author manuscript, peer reviewed version

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Control and experimental characterization of a methanol reformer for a 350W high temperature polymer electrolyte membrane fuel cell system

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Introduction

High temperature polymer electrolyte membrane(HTPEM) fuel cells offer many advantages due to their increased operating temperatures compared to similar Nafion-based membrane technologies, that rely on the conductive abilities of liquid water. The polybenzimidazole (PBI) membranes are especially suited for reformer systems, where high CO tolerance is required. This enables the use fuels based on e.g. liquid alcohols. This work presents the control strategies of a methanol refoermer for a 350W HTPEM FC system. The system examined is the Serenergy H3-350 Mobile Battery Charger, an integrated system, which is shown in figure 1.

Figure 1: The Serenergy H3-350 Mobile Battery Charger; an integrated 350W HTPEM fuel cell system fuelled through a methanol reformer [www.serenergy.dk].

In order to characterize the performance of the methanol reformer in the FC system, the reformer module is separated from the fuel cell stack, to enable more precise measurements of the reformer itself, disconnecting the influence and limitations imposed by the fuel cell stack. Examining exclusively the reformer system will also enable the mapping of the evaporator independently of the fuel cell cathode exhaust air, and the capabilities of the burner supplying heat for the reforming process. The motivation for this analysis is the characterization of the reformer system, both transient and steady-state in order to properly know the limitations of the system and enable the development of efficient control algorithms, to suit the different application demands that such systems are used in. A picture of the experimental setup is shown in figure 2.

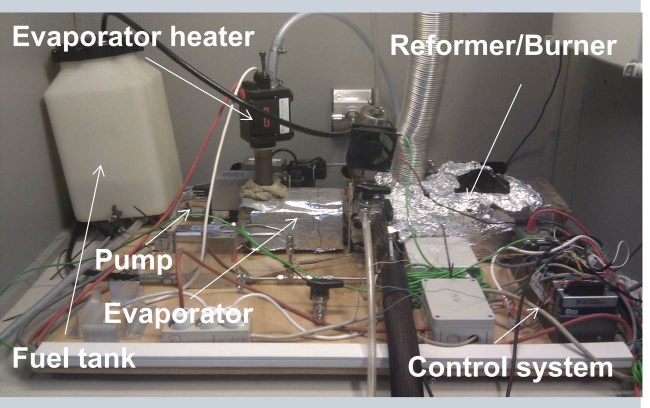

Figure 2: An experimental setup of the methanol reformer including evaporator.

Steam reforming of methanol for a HTPEM fuel cell stack

The experimental system consists of a membrane fuel pump for pumping the 60% (vol.) methanol/ 40% (vol.) deionised water mixture. The mixture initially enters an evaporator where heating, evaporation and superheating is carried out, primarily by the hot fuel cell cathode exhaust air during normal operation, and electrical heaters during start-up. The evaporated fuel mixture afterwards enters the methanol reformer, where it is reformed into a hydrogen rich gas containing also CO, CO_2 water and unconverted methanol. The heat required for the steam reforming process is transferred by burning the exhaust fuel cell anode gas in an integrated burner inside the methanol reformer. The schematics of the experimental setup can be seen in figure 3.

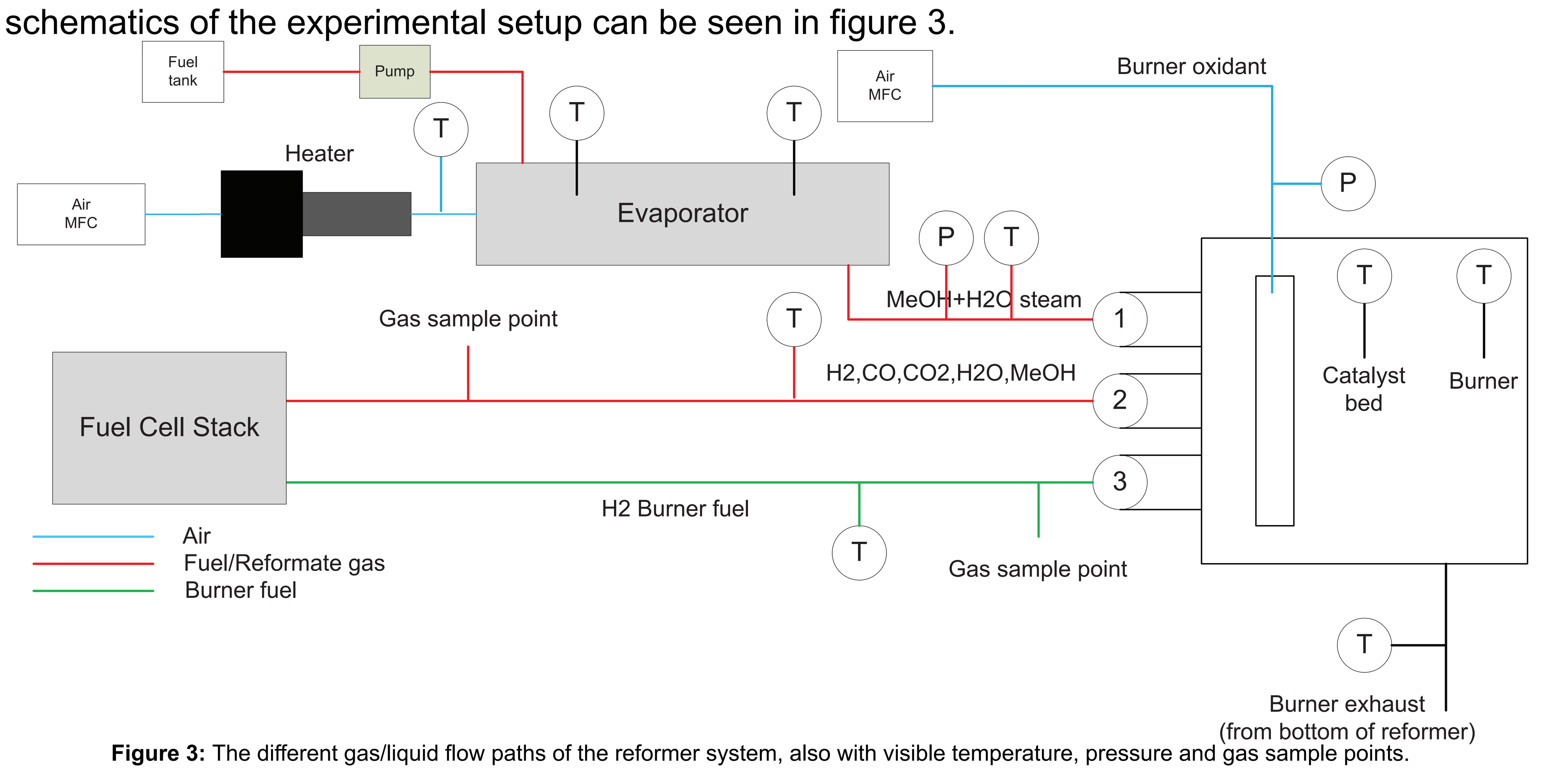

Figure 3: The different gas/liquid flow paths of the reformer system, also with visible temperature, pressure and gas sample points.

In order to examine the performance of the system a series of primary input variables are defined, and a set of different measurement conditions are fixed and imposed on the running system. The input variables for the system in the presented measurement data are: methanol/water pump flow, reformer operating temperature, evaporator heating air flow and temperature, and burner hydrogen flow. The resulting temperatures, flows, and gas concentrations of the system can be seen in figure 4,5 and 7.

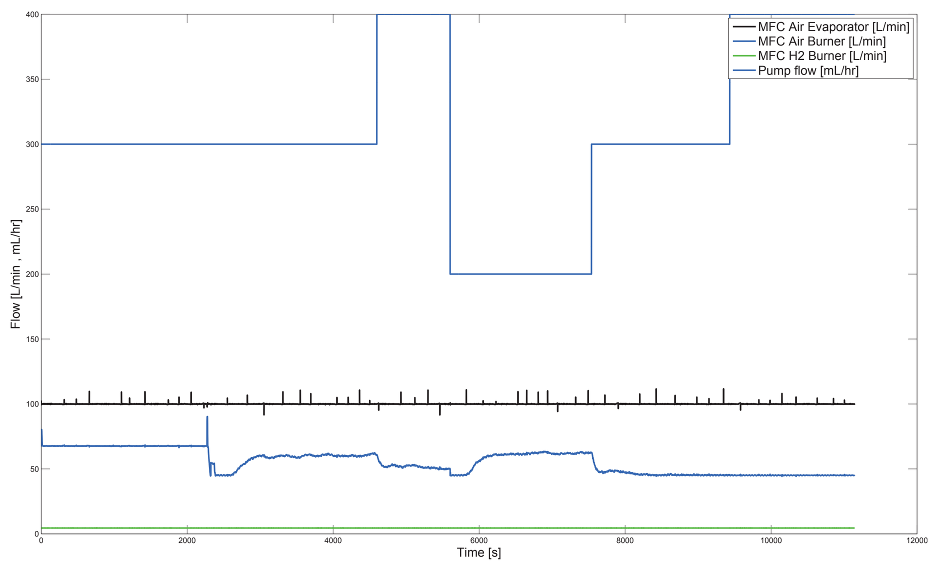

Figure 4: The different gas/liquid flows of the system during the test series.

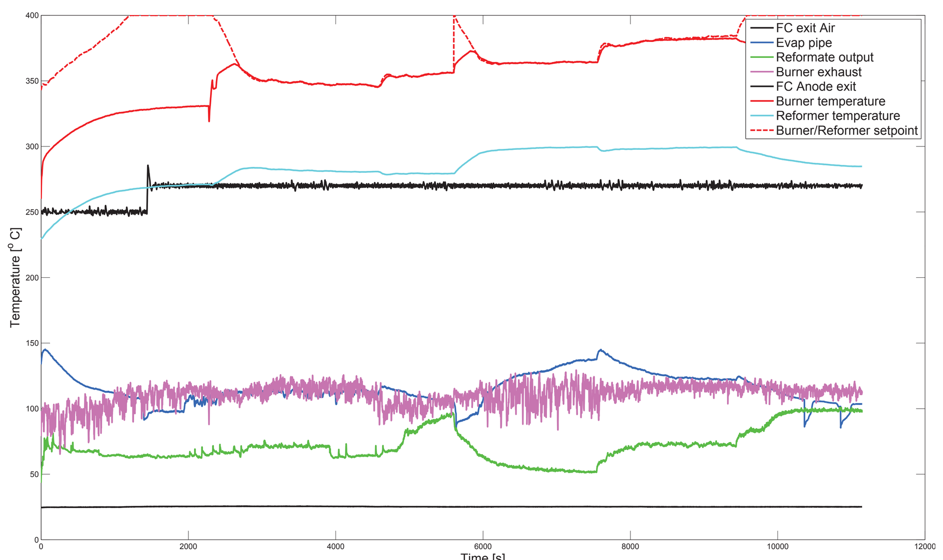

Figure 5: The operating temperatures of the methanol reformer system, including some controller set points.

The set of measurements conducted starts out with an initial heating of the system and fuel flow of 300 mL/hr, where the reformer temperature is settled at 260ºC and 270ºC in order to evaluate the gas output at this operating point. After this, the fuel flow is shortly set to 400 mL/hr in order to test the effect this operation has on the unconverted methanol in the outlet reformate gas. Afterwards the temperature is changed to 280ºC, where the gas composition is evaluated at 200, 300 an 400 mL/hr. During the last of the examined fuel flows, the system was unable to remain at the desired temperature due to higher heat requirements than delivered by the 4,5 L/min hydrogen, which was used throughout the tests. During the presented tests some of the system states were kept constant in order to minimize their interference with the captured results. The tests shown were primarily used to validate the system control strategy of the reformer temperature. The reformer temperature control is carried out as a cascade PID control, as shown in figure 6.

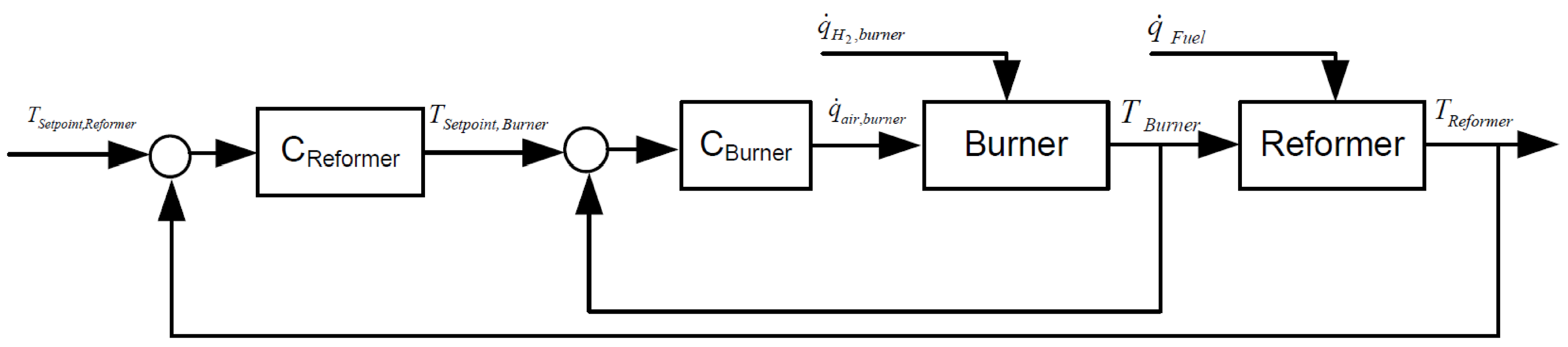

Figure 6: The reformer temperature is controlled by two control loop in a cascade control structure, the inner loop controlling the burner temperature, which is has a faster dynamic characteristic than the reformer temperature, which in the outer loop is controlled by slowly adjusting the burner temperature.

The reformer temperature is affected by many disturbances, the burner temperature, the fuel flow, the methanol conversion process and multiple heat losses in the system. In order to control this temperature, the cascade control strategy was chosen in order to test a strategy with capabilities of improving the speed and precision at which the reformer temperature could be controlled. As seen in figure 5, the burner set point, and the actual burner temperature act fast once step is imposed on the reformer set point temperature. The air flow to the burner is adjusted to meet the burner set point temperature. Meanwhile the slower acting reformer temperature controller adjusts the burner set point to finally enable control of the reformer temperature.

Conclusions

The experimental setup developed is able to conduct detailed measurements of the performance of the methanol reformer system. This can provide vital information of the critical operating parameters of such a system, including the transient behavior of the different state variable that all play an important role in predicting the usable hydrogen output by the system, and just as important; the content of different pollutants, including CO and residual unconverted methanol. Such results, and models able to predict this behavior are important when designing control strategies. The gas concentrations measured during the tests can by seen in figure 7, below.

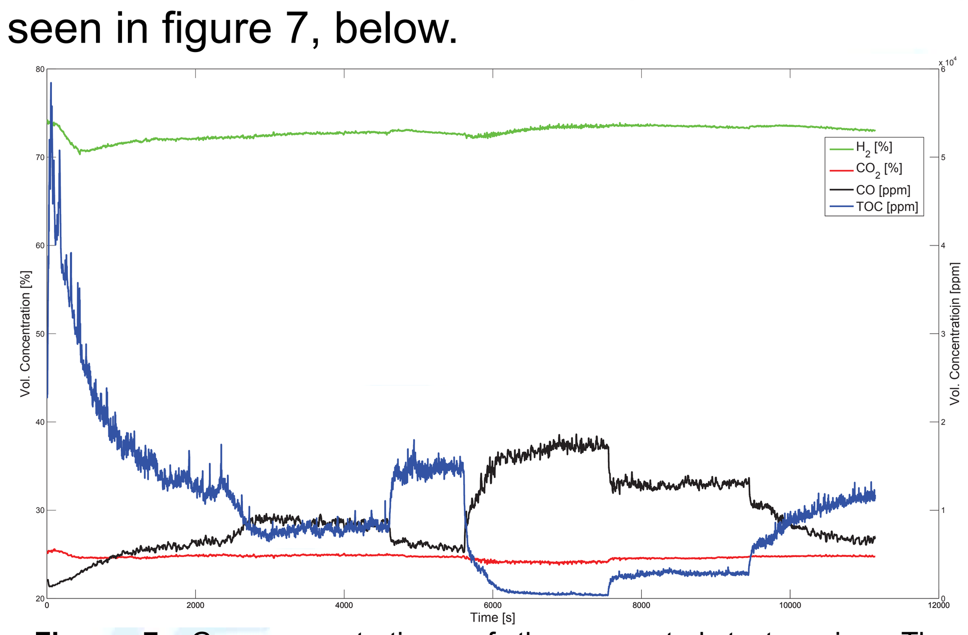

Figure 7: Gas concentrations of the presented test series. The hydrogen, CO2 and CO measurements shown are based on a gas sample where all liquid has been condensed, i.e. dry gas measurement. Whereas TOC shows the methanol content of the wet gas sample.

The resulting output gas of the reformer show a hydrogen content of around 72%, increasing slightly with increasing temperature. An important contaminant in the gas is CO, which, even in HTPEM fuel cell affect the performance. It is seen that the CO content varies between 1-2000 ppm to as high as 20000 ppm in the presented measurements. These are all within acceptable ranges for the BASF P2100 HTPEM fuel cells used in the Serenergy H3-350, but depend much on the reformer temperature, and can easily double quite fast if proper control of the system is not prioritized and taken into consideration. The same is valid for the unconverted methanol, which affect on fuel cell lifetime is still unclear.

Future Work

The further work with the presented experimental setup include a detailed analysis of system operating range, identifying the upper and lower bounds of operation. This is important in order to structure the start-up and shut-down scheduling of the system. Such an analysis would e.g. be able to identify the minimum fuel pump flow, which depends on the available heat transferred from the fuel cell exhaust air to the evaporator. Further more an analysis of transient system capabilities will be conducted to develop simulation models that can be used in designing optimal system control structures with respect to e.g. load change speed, system efficiency, low and CO content. Being able to make online predictions of the important system states is expected to increase the lifetime of such system, if combined with advanced control strategies.

The integration of fuel cell stack and the reformer will play an important role in the next phase of the system testing, and is also required for evaluating the validity and relevance of the developed controllers. It is expected that different control approaches should be matched to the particular application and its requirements.

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